Comment on "Linguistic Features of Noncoding DNA Sequences"

N. E. Israeloff, M. Kagalenko, and K. Chan

israeloff@nuhub.neu.edu, mkagalen@lynx.dac.neu.edu, kechan@lynx.dac.neu.edu

Dept. of Physics

Northeastern University

Boston MA 02115

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In a recent letter [1], Mantegna et. al. report that certain statistical signatures of natural language can be found in non-coding DNA sequences. The vast majority of DNA in higher organisms including humans consists of non-coding sequences whose function, if any, is unknown. Hence this new analysis is quite important. It suggests, as the authors concluded, "the possible existence of one (or more than one) structured biological language(s) present in non-coding DNA sequence". Previous work from this group and others also showed that DNA sequences have long-range power-law correlations [2] [3], which are found in non-coding regions but not in coding regions [2].

Since disorder or randomness dominates many natural phenomena which exhibit power-law correlations it is reasonable to ask whether such correlations alone can produce the statistical features attributed to the presence of language. Here we show that random noise with power-law correlations, similar to the ubiquitous "1/f" noise, exhibits the same "linguistic" statistical signatures reported in ref. 1 for non-coding DNA. We conclude that these signatures by themselves cannot distinguish language from noise.

As in ref. 1 we carried out the Zipf analysis of "word" frequency vs. rank as well as the Shannon analysis of redundancy. Noise with spectral density of the form $S(f) \sim f^{-\beta}$ was analyzed. The exponent β can be related to the exponent α used in the DNA walk correlation analysis by $\beta = 2\alpha - 1$. [2] [4] Noise was synthesized by numerically filtering white-noise with a power-law filtering function. The white noise was derived from either a gaussian random number generator or from amplified thermal noise from a 1 MΩ resistor, with no difference in outcome. We also analyzed $1/f$ noise from a Josephson junction, which had the same statistical behavior as synthesized noise. [5] Signals were binned into four amplitude ranges with equal weight and assigned values

$0-3$ so as to provide a four letter "alphabet", like that of DNA. This method is equivalent to sampling with a 2-bit analog-to-digital converter. The analysis consisted of sampling contiguous blocks of length n (an n-tuple). The n-point sampling window was sequentially shifted by one point until the entire sequence was sampled. The number of occurrences of each such n-tuple was counted, then the n-tuples were ranked from highest to lowest frequency of occurrence.

The Zipf plot of word frequency vs. rank has power-law behavior with exponent $\zeta = -1$ for natural languages. For non-coding DNA ζ ranged from 0.289 to 0.537. [1] Figure 1 shows the Zipf plot for noise with various correlation exponents, β, for 6-tuples from 72k data point sequences. The data cleanly fit a power-law over about three decades, similar to or better than the non-coding DNA results of ref. 1. A monotonic increase in ζ with increasing β is observed as shown in the inset. The power-law scaling breaks down for $\beta \approx 1$ or larger but is recovered when a larger alphabet is used. [5] Also shown are the redundancy percentages, R, for the noise, calculated as in ref. 1. The R values are similar to those in ref. 1 with similar z values.

The best fit to a power-law in a Zipf plot in ref. 1 (fig. 1) is from mammalian DNA with $\zeta = 0.289$. The correlation exponents found for certain mammalian primarily non-coding DNA were in the range $0.64 < a < 0.71$ which give $0.28 < b < 0.42$. [2] By comparison we find $\zeta = 0.28$ for noise with $\beta = 0.30$. This together with the fact that *coding* DNA has $\beta \approx \zeta \approx 0$ are consistent with the idea that power-law correlations without a linguistic component could account for the behavior reported in ref. 1. Our results demonstrate that the Zipf power-law scaling and non-zero Shannon redundancies alone must not be relied upon to distinguish language from noise. However, a detailed comparison of Zipf exponents for DNA, language, and noise with the same correlation exponent

might be revealing. A full account of these findings will appear elsewhere. [5]

Figure Caption

Zipf plot, exponents, and redundancy % for 6-tuples from power-law noise

References

[1] R. N. MANTEGNA, ET. AL., Phys. Rev. Lett. **73**, 3169 (1994).

[2] C. K. PENG, ET. AL., Nature 356, 168 (1992); H. E. Stanley, et. al., Physica **A200**, 4 (1993).

[3] R. VOSS, Phys. Rev. Lett. **68**, 3805 (1992).

[4] After binning, a white component appears in the spectrum.

[5] N. E. ISRAELOFF, M. KAGALENKO, AND K. CHAN to be published.